

## Investigating formation and enrichment processes of the super-large North Sanshandao gold deposit (Jiaodong Peninsula, Eastern China): An in-depth mineralogical perspective

JIAN LI<sup>1,2</sup>, ZHI-MING YANG<sup>2,\*</sup>, MING-CHUN SONG<sup>3</sup>, LEI-LEI DONG<sup>4</sup>, WEN-YAN CAI<sup>1</sup>,  
MING LEI<sup>1</sup>, AND QING-YI CUI<sup>1</sup>

<sup>1</sup>School of Resources and Environmental Engineering, Shandong University of Technology, Zibo 255049, China

<sup>2</sup>Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China

<sup>3</sup>Hebei Key Laboratory of Strategic Critical Mineral Resources, Hebei GEO University, Shijiazhuang 050031, China

<sup>4</sup>University of Science and Technology Beijing, Beijing 100083, China

### ABSTRACT

The formation processes underlying super-large gold deposits present a captivating area of study, with a particularly enigmatic aspect being the mechanisms by which gold forms and accumulates within under-saturated hydrothermal fluids, notably in the presence of thick, high-grade ore bodies. To address this issue, we conducted comprehensive mineral textural, geochemical, isotopic, and machine learning analyses on gold ore-related sulfides from the North Sanshandao gold deposit (~562 t @ 4.35 g/t), which is the second-largest deposit in the world-class Jiaodong gold province, and is recognized as China's inaugural super-large offshore gold resource. The deposit is hosted in the Jurassic Linglong granite and has four stages of alteration and mineralization: (I) quartz-pyrite-K-feldspar; (II) quartz-pyrite-chalcopyrite-native Au; (III) quartz-pyrite-galena-sphalerite-native Au; (IV) ore-barren siderite-ankerite-calcite.

Four types of auriferous pyrite were distinguished, including (stage II) porous Py2a and its Py2b overgrowth, and (stage III) Py3a and its Py3b overgrowth. The gold in Py2a occurs mainly as nanoparticles, whereas Py2b, Py3a, and Py3b contain high contents of lattice gold and coarse-grained native gold, with gold and arsenic contents strongly positively correlated. The characteristics of a porous core and a smooth edge suggest the occurrence of coupled dissolution-reprecipitation (CDR) processes during the early mineralization stage. Low-melting-point chalcophile elements (LMCE, e.g., Bi, Te, Sb) are frequently associated with gold, indicating that the LMCE melt may play a role in the remobilization of gold, in addition to fluids. Combined with the trace element composition, we show that the CDR process led to Au-LMCE liberation and Au remobilization in the ore fluid and LMCE melt. This process may have significantly upgraded the ore, forming large visible gold grains and local high-grade ore zones. Mineral geochemistry of stage I arsenopyrite suggests that the mineralization temperature was 300–400 °C (concentrated from 342–379 °C),  $\log f_{S_2}$  was  $-11.5$  to  $-6.5$  (concentrated from  $-9.5$  to  $-7.5$ ), and  $\log f_{O_2}$  was  $-34.9$  to  $-24.7$  (concentrated from  $-30.2$  to  $-26.7$ ). The sphalerite composition suggests that the temperature dropped by 320 °C during stage III. Both the North Sanshandao gold deposit ( $\delta^{34}S_{V-CDT} = 10.75\text{--}13.31\text{‰}$ ,  $n = 61$ ) and the Jiaodong gold province have high  $\delta^{34}S_{V-CDT}$  values ( $\delta^{34}S_{V-CDT} = 7.1\text{--}10.8\text{‰}$ ,  $n = 1646$  1st and 3rd quartile), implying that sulfate reduction was a key ore-material source. Our study provides a new model for the widespread development of over 80% of the disseminated-type mineralization in the Jiaodong Peninsula, emphasizing Au remobilization as a key factor in the formation of high-grade, high-tonnage ore zones, and sheds new light on multistage ore-material enrichment in large-scale gold mineralization.

**Keywords:** Gold remobilization, coupled dissolution-reprecipitation, multistage ore-material enrichment, North Sanshandao gold deposit, Jiaodong gold province